International Journal of Mathematics and Computer Applications Research (IJMCAR)
ISSN(P): 2249-6955; ISSN(E): 2249-8060
Vol. 4, Issue 2, Apr 2014, 75-88

TRANS STELLAR • Journal Publications • Research Consultancy

UNSTEADY FREE CONVECTION FLOW THROUGH A POROUS MEDIUM PAST A VERTICAL PLATE WITH CONSTANT SUCTION AND HEAT SINK UNDER THE EFFECT OF A MAGNETIC FIELD

L. HARI KRISHNA[1] & R. RAMAKOTESWARA RAO[2]

[1]Assistant Professor, Department of Mathematics, Annamacharya Institute of Technology & Science, Rajampeta, Kadapa, Andhra Pradesh, India

[2]Principal, Annamacharya Institute of Institute of Technology & Science, Rajampeta, Kadapa, Andhra Pradesh, India

ABSTRACT

In this paper, the unsteady MHD free convective flow through a porous medium bounded by an infinite vertical porous plate with heat sink is investigated. Approximate solution for the velocity field, temperature field, mean skin friction and mean rate of heat transfer are obtained. The effects of various emerging parameters on the velocity field, temperature field, mean skin friction and mean rate of heat transfer are discussed through graphs and tables in detail.

KEYWORDS: MHD, Darcy Number, Source, Heat Sink

1. INTRODUCTION

The problems in heat transfer have so many applications in Engineering Sciences such as the design of cooling systems for motors, generators and transformers. Chemical engineers are concerned with the evaporation, condensation, heating and cooling of fluids. An understanding of the laws of heat flow is important to structures and to the architect in the design of buildings. To estimate the cost, the feasibility and the size of the equipment necessary to transfer a specific amount of heat in a given time, detailed heat transfer analysis must be made. The dimensions of boilers, heaters, refrigerators and heat exchangers depend not only on the amount of heat to be transmitted but rather on the rate at which heat is to be transmitted under given conditions. It follows that in almost every branch of engineering, heat transfer problems are encountered which cannot be solved by thermodynamic reasoning alone but require an analysis based on the science of heat transfer.

In the recent years, the problem of free convective unsteady flow through a porous medium bounded by an infinite vertical porous plate has attracted the attention of number of researcher because of its possible application in design of steam displacement process in an oil recovery and various geothermal systems. The free convective unsteady flow past an infinite porous plate with heat source was studied by Pop and Soundalgekhar [1]. Free convective flow of a electrically conducting fluids past a semi-infinite flat plate under influence of a magnetic field has been studied by Gupta [2] and Singh and owling [3]. MHD free convective flow with Hall current in a porous medium for electro solution was analyzed by Sattar and Alam [4]. Sahoo et al. [5] have studied MHD unsteady free convective past an infinite vertical plate with constant suction and heat sink.

The study of unsteady hydro magnetic free convection flow of viscous incompressible and electrically conducting fluid past an infinite vertical porous plate in presence of constant suction and heat absorbing sinks has been discussed by

Sahoo et al. [5]. Approximate solutions have been derived using multi-parameter perturbation technique. It is observed the increase in magnetic field strength decrease with increase in magnetic field strength. The hydro magnetic mixed convection flow of an incompressible viscous electrically conducting fluid and mass transfer over a vertical porous plate with constant heat flux embedded in a porous medium was investigated by Makinle [6]. Using the Boussinesq and boundary-layer approximation, the fluid equations for momentum, energy balance and concentration governing the problem are formulated. It was found that for positive values of the buoyancy parameters, the skin friction increased with increasing values of both the Eckert number and the magnetic field intensity parameter and decreased with increasing values of both the Schmidt number and permeability parameter.

In view of these, in this paper we studied the MHD free convective unsteady flow through a porous medium bounded by an infinite vertical porous plate with heat sink. Approximate solution for the velocity field, temperature field, mean skin friction and mean rate of heat transfer are obtained. The effects of various emerging parameters on the velocity field, temperature field, mean skin friction and mean rate of heat transfer are discussed through graphs and tables in detail.

2. NOMENCLATURE

g	: Acceleration due to gravity
β	: Coefficient of volume expansion
σ	: Conductivity of the medium
$Ec = \dfrac{V_0'^2}{C_p(T_w' - T_\infty')}$	: Eckert number
ν	: Kinematic viscosity
B_0	: Magnetic induction
ρ	: Fluid density
$Gr = \dfrac{\nu g \beta (T_w' - T_\infty')}{V_0'^3}$	: Grashoff number
$M = \left(\dfrac{\sigma B_0^2}{\rho}\right)\dfrac{\nu}{V_0'^2}$	: Magnetic Parameter
k	: Permeability of the porous medium
$Pr = \dfrac{\mu C_p}{\kappa}$	: Prandtl number
$S = \dfrac{4S'\nu}{V_0'^2}$	: Sink Strength parameter

C_p	: Specific heat at constant pressure
V_0'	: Suction velocity
T'	: Temperature
κ	: Thermal conductivity
t'	: Time
$(u', v', 0)$	: Velocity of the fluid
V'	: Velocity of the fluid along the y' Direction

3. MATHEMATICAL FORMULATION

We consider the flow of an incompressible viscous and electrically conducting fluid through porous medium past an infinite vertical porous plate in the presence of constant suction and heat absorbing sinks. Let the x' - axis be taken along the plate and y' - axis normal to the plate. The fluid subjected to a constant transverse magnetic field of strength B_0. Neglecting the induced magnetic field and Boussinesq's approximation, the equations governing the flow can be written as:

Equation of Continuity:

$$\frac{\partial V'}{\partial y'} = 0 \tag{3.1}$$

That is $V' = V_0'$ (constant) (3.2)

Equation of Momentum:

$$\frac{\partial u'}{\partial t'} + V'\frac{\partial u'}{\partial y'} = g\beta(T' - T_\infty') + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{k}u' \tag{3.3}$$

Equation Energy:

$$\frac{\partial T'}{\partial t'} + V'\frac{\partial T'}{\partial y'} = \frac{K}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + S'(T' - T_\infty') + \frac{\nu}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{3.4}$$

On disregarding the Joulean heat dissipation. The boundary conditions are given by

$$u' = 0,\quad V' = -V_0',\quad T' = T_w' + \varepsilon\left(T_w' - T_\infty'\right)e^{i\omega' t'} \text{ as } y' \to 0$$

$$u' \to 0,\; T' \to T_\infty' \text{ as } y' \to \infty \tag{3.5}$$

Here u' is the velocity of the fluid in the upward direction, V' is the velocity fluid along the y' - axis, V_0' is the

suction velocity (constant), t' is the time, g is the acceleration due to gravity, β is the coefficient of volume expansion, ν is the kinematic viscosity, ρ is the fluid density, σ is the electrical conductivity, B_0 is constant transverse magnetic field, k is the permeability of the porous medium, S' is the heat sink strength, T' is the temperature of the fluid near the Plate, C_p is the specific heat at constant pressure and K is the thermal conductivity.

Introducing the following non - dimensional variables

$$y = \frac{y'V_0'}{\nu},\ t = \frac{t'V_0'^2}{4\nu},\ \omega = \frac{4\nu\omega'}{V_0'^2},\ u = \frac{u'}{V_0'},\ \nu = \frac{\mu}{\rho}, T = \left(\frac{T'-T_\infty'}{T_w'-T_\infty'}\right),\ \Pr = \frac{\mu C_p}{K},\ S = \frac{4S'\nu}{V_0'^2},$$

$$G = \frac{\nu g\beta\left(T_w'-T'\right)_\infty}{V_0'^3},\ Ec = \frac{V_0'^2}{C_p(T_w'-T_\infty')}, M = \left(\frac{\sigma B0^2}{\rho}\right)\frac{\nu}{V_0'^2},\ V = \frac{V'}{V_0'}, D = \frac{\nu^2}{kV_0'^2} = \frac{1}{Da} \tag{3.6}$$

Where Pr, G, S, Ec and M are respectively the prandtl number, Grashof number, Sink strength, Eckert number and Hartmann number With the help of equation (3.5) and equation (3.6), equation (3.2) and (3.3) become

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = G.T + \frac{\partial^2 u}{\partial y^2} - Mu - Du \tag{3.7}$$

And $$\frac{\Pr}{u}\frac{\partial T}{\partial t} - \Pr\frac{\partial T}{\partial y} = \frac{\partial^2 T}{\partial y^2} + \frac{\Pr}{4}ST + \Pr Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{3.8}$$

And the modified boundary conditions are

$u = 0$, $T = 1 + \varepsilon e^{i\omega t}$ at $y = 0$

And $u \to 0$, $T \to 0$ as $y \to \alpha$ (3.9)

To solve equation (3.7) and (3.8), we assume ε to be very small and the velocity and temperature in the neighborhood of the plate as Solution of the Problem

$$u(y,t) = u_0(y) + \varepsilon e^{i\omega t}u_1(y) \text{ and } T(y,t) = T_0(y) + \varepsilon e^{i\omega t}T_1(y) \tag{3.10}$$

Putting (3.10) in equation (3.7) and (3.8), equating harmonic and non-harmonic terms and neglecting the co-efficient of ε^2, we get

$$\frac{\partial^2 u_0}{\partial y^2} + \frac{\partial u_0}{\partial y} - (M + D)u_0 = -GT_0 \tag{3.11}$$

$$\frac{\partial^2 u_1}{\partial y^2} + \frac{\partial u_1}{\partial y} - \left(M + D + \frac{i\omega}{4}\right)u_1 = -GT_1 \tag{3.12}$$

Equations Hamic, Non-Hamic, Equation

$$\frac{\partial^2 T_0}{\partial y^2}+\Pr\frac{\partial T_0}{\partial y}+\frac{\Pr S}{4}T_0=-\Pr Ec\left(\frac{\partial u_0}{\partial y}\right)^2 \tag{3.13}$$

$$\frac{\partial^2 T_1}{\partial y^2}+\Pr\frac{\partial T_1}{\partial y}-\frac{\Pr}{4}(i\omega-S)T_1=-2\Pr Ec\left(\frac{\partial u_0}{\partial y}\right)\left(\frac{\partial u_1}{\partial y}\right) \tag{3.14}$$

Using multi parameter perturbation technique and assuming $Ec<<1$, we write,

$$u_0=u_{00}+Ec\ u_{01},\quad T_0=T_{00}+Ec\ T_{01} \tag{3.15}$$

$$u_1=u_{10}+Ec\ u_{11},\quad T_1=T_{10}+Ec\ T_{11} \tag{3.16}$$

Using equation (3.15) and (3.16) in the equations (3.11) – (3.14) and equating the coefficients of Ec^1 and Ec^1 only, we get the following sets of differential equations for $u_{00},u_{01},u_{10},u_{11}$ and $T_{00,}T_{01},T_{10},T_{11}$,

$$u_{00}''+u_{00}'-(M+D)u_{00}=-GT_{00} \tag{3.17}$$

$$u_{01}''+u_{01}'-(M+D)u_{01}=-GT_{01} \tag{3.18}$$

$$u_{10}''+u_{10}'-\left(M+D+\frac{i\omega}{4}\right)u_{10}=-GT_{10} \tag{3.19}$$

$$u_{11}''+u_{11}'-\left(M+Da+\frac{i\omega}{4}\right)u_{11}=-GT_{11} \tag{3.20}$$

And $T_{00}''+\Pr T_{00}'+\frac{\Pr S}{4}T_{00}=0$ (3.21)

$$T_{01}''+\Pr T_{01}'+\frac{\Pr S}{4}T_{01}=-\Pr(u_{00}')^2 \tag{3.22}$$

$$T_{10}''+\Pr T_{10}'-\frac{\Pr}{4}(i\omega-S)T_{10}=0 \tag{3.23}$$

$$T_{11}''+\Pr T_{11}'-\frac{\Pr}{4}(i\omega-S)T_{11}=-2\Pr(u_{00}'u_{10}') \tag{3.24}$$

Solving these differential equations (3.17) – (3.24) with aid of the corresponding boundary conditions and then substituting the values in the relations (3.15) and (3.16), we obtain the mean velocity u_0 and mean temperature T_0 as well as u_1,T_1 as

$$u_0=\left\{\frac{G}{(a_2^2-a_2-M-D)}+EcX_1\right\}e^{-a_4 y}-\frac{G}{(a_2^2-a_2-M-D)}\left\{1+\frac{Ec\Pr G^2 X}{(a_2^2-a_2-M-D)^2}\right\}e^{-a_2 y}$$

$$+\frac{\Pr EcG^3D_4}{(a_2^2-a_2-M-D)^2}e^{-2a_4y}+\frac{Ec\Pr G^3D_5}{(a_2^2-a_2-M-D)^2}e^{-2a_2y}-\frac{Ec\Pr G^3D_6}{(a_2^2-a_2-M-D)^2}e^{-(a_2+a_4)y} \quad (3.25)$$

$$u_1=\left\{\frac{G}{\left[a_6^2-a_6-(M+D+\frac{i\omega}{4})\right]}+EcX_4\right\}e^{-a_8y}-\frac{G}{\left[a_6^2-a_6-(M+D+\frac{i\omega}{4})\right]}\left\{1+2E_c\Pr X_2X_3\right\}e^{-a_6y}$$
$$+Ec2G\Pr X_2\left[D_{11}e^{-(a_4+a_8)y}-D_{12}e^{-(a_4+a_6)y}-D_{13}e^{-(a_2+a_8)y}+D_{14}e^{-(a_2+a_6)y}\right] \quad (3.26)$$

$$T_0=\left\{1+\frac{\Pr EcXG^2}{(a_2^2-a_2-M-D)^2}\right\}e^{-a_2y}-\frac{\Pr EcG^2}{(a_2^2-a_2-M-D)^2}\left\{D_1e^{-2a_4y}+D_2e^{-2a_2y}-D_3e^{-(a_2+a_4)y}\right\} \quad (3.27)$$

$$T_1=e^{-a_6y}+Ec\left\{2\Pr X_2X_3e^{-a_6y}-2\Pr X_2\left[D_7e^{-(a_4+a_8)y}-D_8e^{-(a_4+a_6)y}-D_9e^{-(a_2+a_8)y}-D_{10}e^{-(a_2+a_6)y}\right]\right\}$$

(3.28)

Where

$$a_2=\frac{1}{2}(\Pr+\sqrt{\Pr^2-\Pr S}),\ a_4=\frac{1}{2}\left(1+\sqrt{1+4M+4D}\right),\ a_6=\frac{\Pr+\sqrt{\Pr^2-i\Pr\omega+\Pr S}}{2},$$

$$a_8=\frac{1+\sqrt{1+4\left(M+D+\frac{i\omega}{4}\right)}}{2},\ D_1=\frac{a_4^2}{4a_4^2-2\Pr a_4+\frac{\Pr S}{4}},D_2=\frac{a_2^2}{4a_4^2-2\Pr a_2+\frac{\Pr S}{4}},$$

$$D_3=\frac{2a_2a_4}{(a_2+a_4)^2-\Pr(a_2+a_4)+\frac{\Pr S}{4}},D_4=\frac{D_1}{(4a_4^2-2a_4-M-D)},\ D_5=\frac{D_2}{(4a_2^2-2a_2-M-D)},$$

$$D_6=\frac{D_3}{\left[(a_2+a_4)^2-(a_2+a_4)-M-D\right]},\ D_7=\frac{a_4a_8}{\left[(a_4+a_8)^2-\Pr(a_4+a_8)-\frac{\Pr}{4}(i\omega-S)\right]},$$

$$D_8=\frac{a_4a_6}{\left[(a_4+a_6)^2-\Pr(a_4+a_6)-\frac{\Pr}{4}(i\omega-S)\right]},\ D_9=\frac{a_2a_8}{\left[(a_2+a_8)^2-\Pr(a_2+a_8)-\frac{\Pr}{4}(i\omega-S)\right]},$$

$$D_{10}=\frac{a_2a_6}{\left[(a_2+a_6)^2-\Pr(a_2+a_6)-\frac{\Pr}{4}(i\omega-S)\right]},\ D_{11}=\frac{D_7}{\left[(a_4+a_8)^2-(a_4+a_8)-(M+D+\frac{i\omega}{4})\right]},$$

$$D_{12} = \frac{D_8}{\left[(a_4+a_6)^2-(a_4+a_6)-(M+D+\frac{i\omega}{4})\right]},\ D_{13} = \frac{D_9}{\left[(a_2+a_8)^2-(a_2+a_8)-(M+D+\frac{i\omega}{4})\right]},$$

$$D_{14} = \frac{D_{10}}{\left[(a_2+a_6)^2-(a_2+a_6)-(M+D+\frac{i\omega}{4})\right]},\qquad X = D_1+D_2-D_3,$$

$$X_1 = \frac{\Pr G^3 X}{(a_2^2-a_2-M-D)^3}-\frac{\Pr G^3}{(a_2^2-a_2-M-D)^2}\{D_4+D_5-D_6\},,$$

$$X_2 = \frac{G^2}{\left(a_2^2-a_2-M-D\right)\left(a_6^2-a_6-M-D-\frac{i\omega}{4}\right)},\ X_3 = D_7-D_8-D_9+D_{10}$$

And $X_4 = \dfrac{2G\Pr X_2X_3}{a_6^2-a_6-(M+D+\frac{i\omega}{4})}-2G\Pr X_2\left[D_{11}-D_{12}-D_{13}+D_{14}\right]$

Skin Friction

The skin friction at the plate in dimensionless form is given by

$$\tau_w = \left(\frac{\partial u}{\partial y}\right)_{y=0} = u_0'(0)+\varepsilon e^{i\omega t}u_1'(0) \tag{3.29}$$

Rate of Heat Transfer

The rate of heat transfer at the plate is given by

$$q_w = \left(\frac{\partial T}{\partial y}\right)_{y=0} = T_0'(0)+\varepsilon e^{i\omega t}T_0'(0) \tag{3.30}$$

4. RESULTS AND DISCUSSIONS

Figure 1- 4 show the profiles of mean velocity and transient velocity. Figure1 shows the effects of Prandtl number Pr and Hartmann number on the mean velocity u_0. It is found that, the mean velocity is greater for mercury $(Pr = 0.025)$ than that of electrolytic solution $(Pr = 1.0)$. Also, it is observed that the mean velocity decreases with an increase in Hartmann number M. The effect of Darcy number Da on the mean velocity is shown in Figure 2 with fixing $G = 5,\ E_c = 0.001,\ \omega = 5,\ S = -0.05,\ Pr = 1$ and $M = 1$. It is observed that the mean velocity is increases with increasing Darcy number Da.

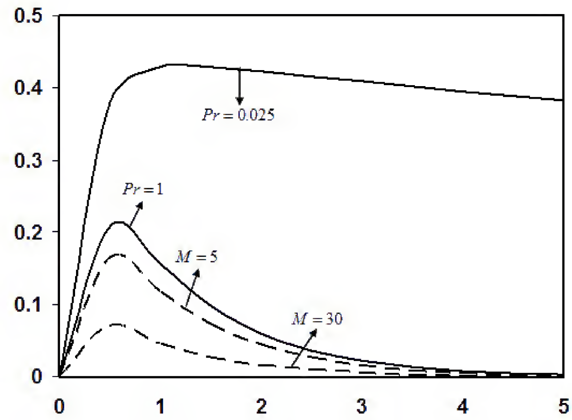

Figure 1: Effect of *Pr* and *M* on Mean Velocity for *G*=5, E_c=0.001, ω=5, S=-0.05 and *Da*=0.1

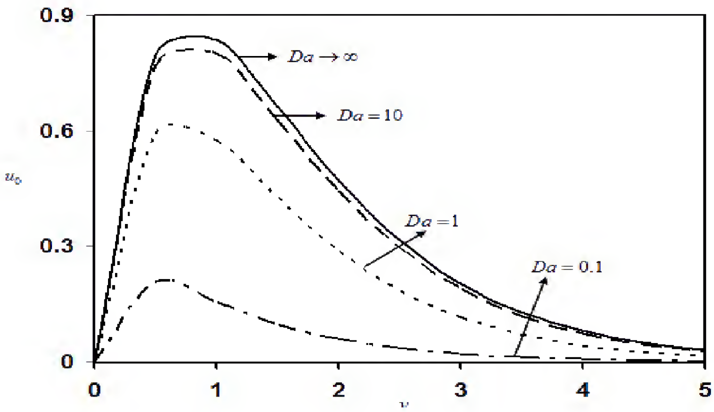

Figure 2: Effect of *Da* on Mean Velocity for *G*=5, E_c=0.001, ω=5, *S*=-0.05, Pr=1, *M*=1

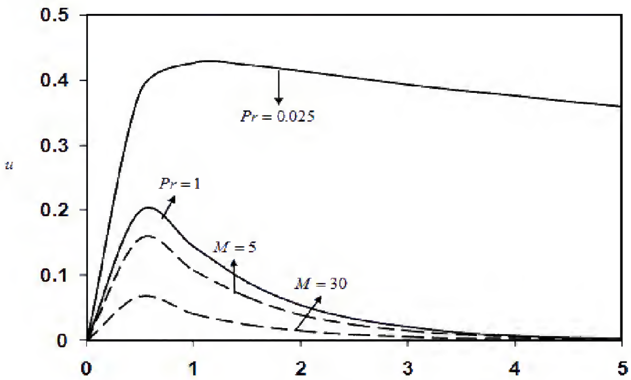

Figure 3: Effect of *Pr* and *M* on Transient Velocity for *G*=5, E_c=0.001, ω=5, *S*=-0.05 and *Da*=0.1

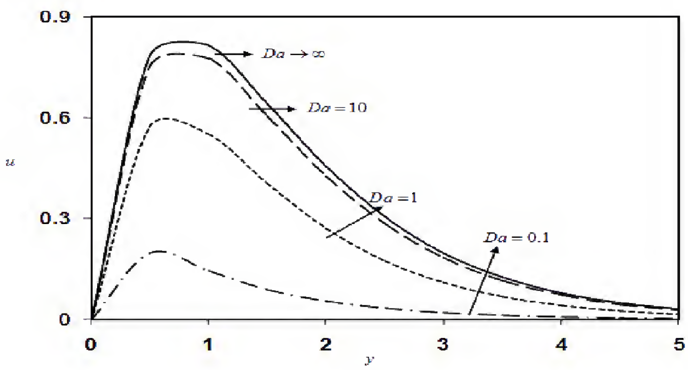

Figure 4: Effect of *Da* on Transient Velocity for *G*=5, E_c=0.001, ω=5, S=-0.05, *Pr*=1, *M*=1

Figure 3 represents the effects of Prandtl number Pr and Hartman number M on the transient velocity u. It is found that, the transient velocity u decreases with increasing Pr. Also, it is observed that, the transient velocity decreases with an increase in M. The effect of Darcy number Da on transient velocity u is shown in Figure 4 by fixing $G=5,\ E_c=0.001,\ \omega=5,\ S=-0.05,\ Pr=1$ and $M=1$. It is observed that, with the increases in Da increases the transient velocity.

Figure 5 depicts the effect of Prandtl number Pr on the mean temperature T_0. It is found that, the mean temperature decreases with increasing Pr. The effect of Prandtl number Pr on the transient temperature T for $G=5,\ E_c=0.001,\ \omega=5,\ S=-0.05,\ M=1$ and $Da=0.1$ is shown in Figure 6. It is observed that, the transient temperature decrease with increasing Pr.

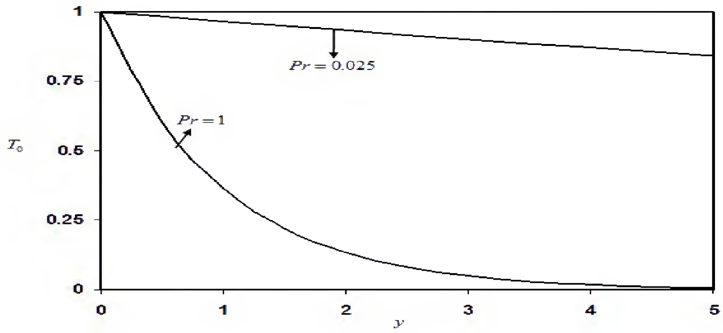

Figure 5: Effect of *Pr* on Mean Temperature T_0 for *G*=5, E_c=0.001, ω=5, *S*=-0.05, *M*=1 and *Da*=0.1

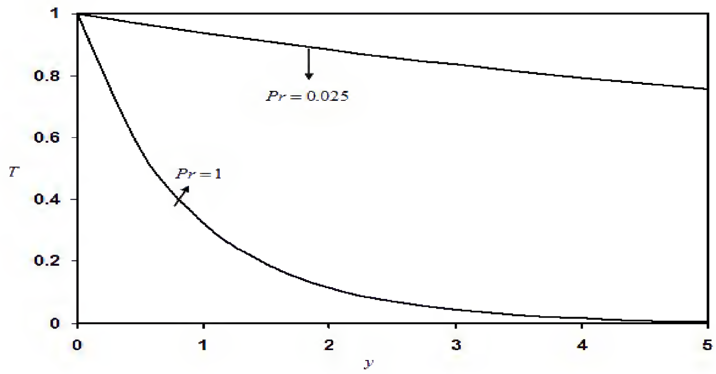

Figure 6: Effect of *Pr* on Transient Temperature *T* for *G*=5, E_c=0.001, ω=5, *S*=-0.05, *M*=1 and *Da*=0.1

Figure 7 depicts the effect of Hartmann number M on the mean skin friction τ_w. It is observed that, with increase in magnetic field strength decreases the mean skin friction. Figure 8 represents the effect of sink strength S on mean skin friction τ_w for $G=5,\ E_c=0.001,\ \omega=5,\ M=1,\ Pr=1$ and $Da=0.1$. It is observed that, the mean skin friction decreases with increasing sink strength S.

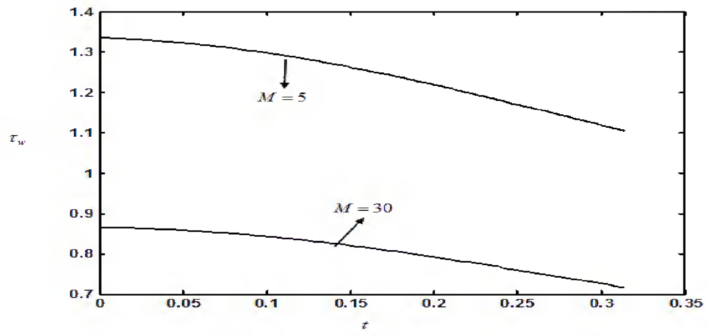

Figure 7: Effect of *M* on Mean Skin Friction τ_w for *G*=5, E_c=0.001, ω=5, *S*=-0.1, Pr=1 and *Da*=0.1

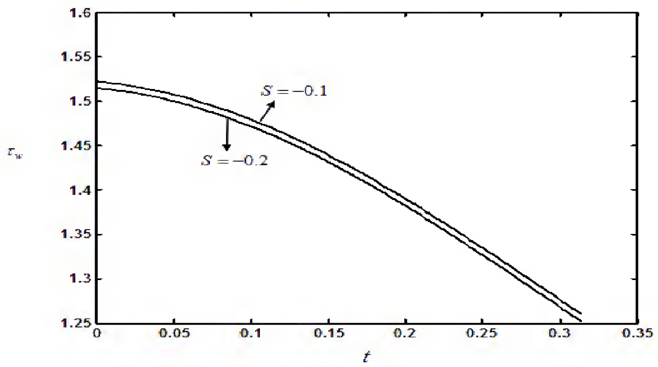

Figure 8: Effect of *S* on Mean Skin Friction for G=5, E_c=0.001, ω=5, *S*=-0.1, Pr=1 and *Da*=0.1

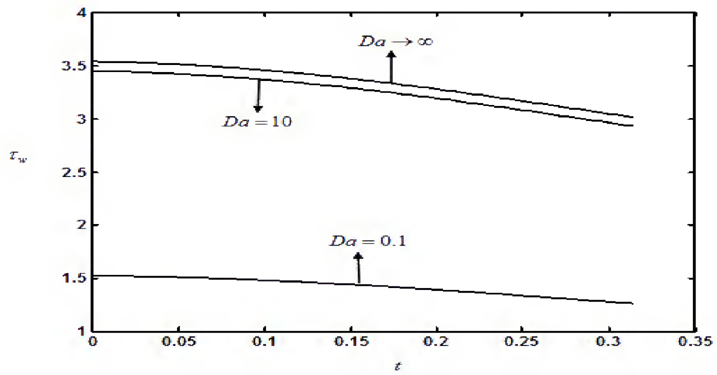

Figure 9: Effect of *Da* on Man Skin Friction for *G*=5, E_c=0.001, ω=5, *M*=1, *Pr*=1 and *S*=-0.1

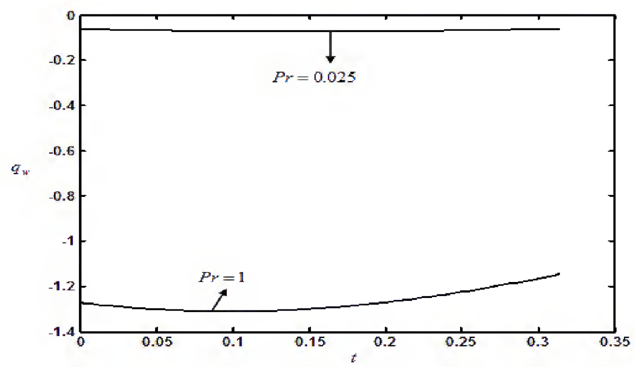

Figure 10: Effect of *Pr* on Mean Rate of Heat Transfer for *G*=5, E_c=0.001, ω=5, *S*=-0.1 and *Da*=0.1

The effect of Darcy number Da on the mean skin friction τ_w for $G = 5,\ E_c = 0.001,\ \omega = 5,\ M = 1,\ Pr = 1$ and $S = -0.1$ is shown in Figure 9. It is observed that, the mean skin friction τ_w decreases with on increase in Da. Figure 10 shows the effect of Prandtl number Pr on the mean rate of heat transfer q_w for $G = 5,\ E_c = 0.001,\ \omega = 5,\ S = -0.1$ and $Da = 0.1$. If is found that the mean rate of heat transfer decreases with increasing Pr.

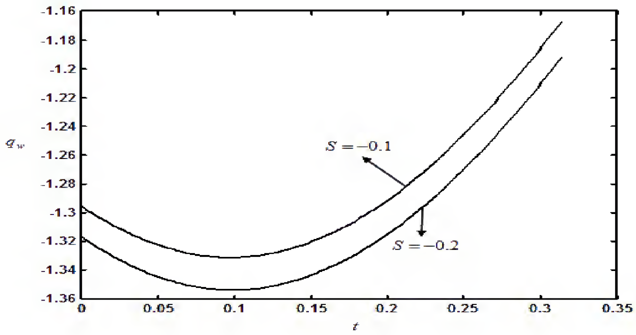

Figure 11: Effect of *S* on Mean Rate of Heat Transfer q_w for *G*=5, *E*$_c$=0.001, ω=5, *Pr*=1, *M*=1 and *Da*=0.1

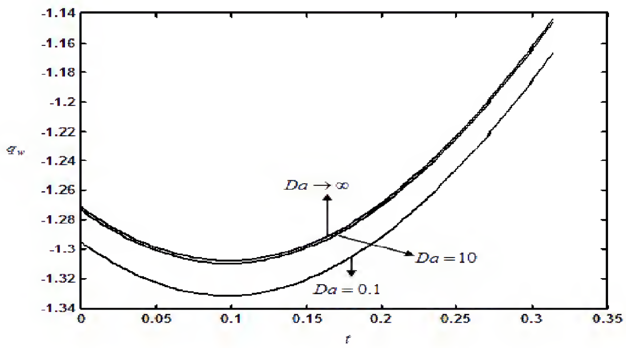

Figure 12: Effect of *Da* on Mean Rate of Heat Transfer q_w for *G*=5, *E*$_c$=0.001, ω=5, *Pr*=1, *S*=-0.1 and *M*=1

Figure 11 depicts the effect of sink strength S on the mean rate of heat transfer q_w for $G = 5,\ E_c = 0.001,\ \omega = 5,\ Pr = 1\ M = 1$ and $Da = 0.1$. It is observed that, with increase in sink strength decreases the mean rate of heat transfer. The effect of Darcy number Da on the mean rate of heat transfer q_w for $G = 5,\ E_c = 0.001,\ \omega = 5,\ Pr = 1\ S = -0.1$ and $M = 1$ is shown in Figure 12. It is observed that the mean rate of heat transfer q_w increases with increasing Darcy number Da

Table 1: Table for Mean Temperature T_0

	$G=5, E_c=0.001, \omega=5, S=-0.05$, and $Da=0.1$		$G=5, E_c=0.001, \omega=5, S=-0.05, Pr=1$ and $M=1$.			$G=5, E_c=0.001, Da=0.1, Pr=1, \omega=5$ and $M=1$	
y	M= 5	M= 30	Da = infinite	Da = 10	Da = 0.1	S = - 0.1	S = - 0.2
0	1	1	1	1	1	1	1
0.5	0.6029	0.6028	0.6052	0.605	0.6029	0.6029	0.6034
1	0.3635	0.3634	0.3657	0.3655	0.3635	0.3635	0.364
1.5	0.2191	0.219	0.2212	0.2211	0.2192	0.2192	0.2195
2	0.1321	0.132	0.1338	0.1337	0.1321	0.1321	0.1324
2.5	0.0796	0.0796	0.0809	0.0808	0.0796	0.0796	0.0798
3	0.048	0.048	0.0489	0.0488	0.048	0.048	0.0481
3.5	0.0289	0.0289	0.0295	0.0295	0.0289	0.0289	0.029
4	0.0174	0.0174	0.0178	0.0178	0.0174	0.0174	0.0175
4.5	0.0105	0.0105	0.0107	0.0107	0.0105	0.0105	0.0105
5	0.0063	0.0063	0.0065	0.0065	0.0063	0.0063	0.0064

Table 2: Table for Mean Temperature T

	$G=5, E_c=0.001, \omega=5, S=-0.05$, and $Da=0.1$		$G=5, E_c=0.001, \omega=5, S=-0.05, Pr=1$ and $M=1$.			$G=5, E_c=0.001, Da=0.1, Pr=1, \omega=5$ and $M=1$	
y	M= 5	M= 30	Da = infinite	Da = 10	Da = 0.1	S = - 0.1	S = - 0.2
0	1	1	1	1	1	1	1
0.5	0.5634	0.5601	0.5639	0.5637	0.5617	0.5632	0.5558
1	0.3252	0.322	0.3253	0.3251	0.3232	0.325	0.3162
1.5	0.1923	0.1901	0.1925	0.1924	0.1906	0.1922	0.1843
2	0.1159	0.1147	0.1162	0.1161	0.1146	0.1159	0.1098
2.5	0.0708	0.0702	0.0711	0.071	0.0699	0.0708	0.0663
3	0.0435	0.0433	0.0437	0.0436	0.0429	0.0435	0.0404
3.5	0.0268	0.0267	0.0268	0.0268	0.0263	0.0268	0.0246
4	0.0164	0.0164	0.0164	0.0164	0.0161	0.0164	0.0149
4.5	0.01	0.01	0.01	0.01	0.0098	0.01	0.009
5	0.0061	0.0061	0.0061	0.006	0.0059	0.0061	0.0054

Table 1 Show the effects of Hartman numbers M, Darcy number Da and sink strength S. It is observed that, with the increase in Hartmann number reduces the mean temperature T_0 slightly. The mean temperature T_0 increases with decreasing sink strength S. Also it is observed that, the mean temperature T_0 increases with increasing Darcy number Da. Table 2 show the effects of Hartmann number M, Darcy number Da and sink strength S on the transient temperature T. It is found that the transient temperature T decreases with an increase in M. Also it is observed that, the transient temperature increases with increasing Da. Also, it is found that with increase in sink strength decreases the transient temperature.

REFERENCES

1. Pop. I and Soundalgekhar, V.M. Int. J. Heat Mass Transfer, vol. 17, 1974, pp. 85.
2. Gupta, A.S., Appl. Sci. Res. Vol. 9A, 1960, pp. 319.
3. Singh. K. R, and T.G. owing, Quart, J. Mech. Appl. Math. Vol.16, 1963a, pp.1.
4. Sattar.Md. A, and Md. M. Alam, IJPAM, vol.26 (2), 1995, pp. 157-67.
5. Sahoo, P.K., N. Datta and S. Biswal, Magneto hydrodynamic unsteady free convection flow past an infinite vertical plate with constant suction and heat sink, Indian J. Pure appl. Math., vol.34(1), 2003, pp.145-155.
6. Makinle. O. D., On MHD boundary-layer flow and mass transfer past a vertical plate in a porous medium with constant heat flux, International journal of Numerical Methods for Heat & Fluid flow, Vol, 19 Nos. ¾, 2009, pp.546-554.

7. Israel-Cookey, C., A. Ogulu and V.B. Omubo-Pepple, International Journal of heat transfer, vol. 46, 2003, pp. 2305-2311.

8. Cookey, C.I., A. Ogulu, V.B. Omubo-Pepple, Int. J. Heat Mass Transfer, vol. 46, 2003, pp. 2305–2311.

9. Kreshna Gopal Singha, P.N. Deka, Skin-Friction for unsteady free convection MHD flow between two heated vertical parallel plates, Theoret. Appl. Mech., Vol. 33, No. 4, 2006, pp. 259-280.

10. MD. Abdus Sattar and MD. Mahmud Alam, MHD free convective heat and mass transfer flow with hall current and constant heat flux through a porous medium, Indian J. Pure appl. Math., vol. 26(2), 1995, pp.157-167.

11. Hossain, M.A., O. Arbad, A numerical study of the unsteady MHD free convection with hall current, Journal of Astrophysics and space science, vol. 141, 1988, pp. 281-291.

12. E.M. Sparrow, and R.D. Cess, (1962), J. Appl. Mech. Trans. of ASME. Vol. 29, No: 1 P.181.

13. V.J. Rossow, (1957), NACA-YN, pp. 3971.

14. Abdus Sattar, Md., Unsteady hydromagnetic free convection flow with hall current mass transfer and variable suction through a porous medium near an infinite vertical porous plate with constant heat flux, International Journal of Energy Research, Vol 18 (9), 2007, pp. 771 – 775.

15. M. C. Raju, S.V.K. Varma, P.V. Reddy, S. Suman, Soret effects due to natural convection between heated inclined plates with Magnetic field, *J. of Mechanical Engg.* 39 (2008) 43-48.

16. M. C. Raju, S. V. K. Varma, R.R.K. Rao, Unsteady MHD free convection and chemically reactive flow past an infinite vertical porous plate, i-manager *Journal of Future Engg*. and Tech. 8 (3) (2013), 35-40.

17. V. Ravikumar, M. C. Raju, G.S.S. Raju, A. J. Chamkha, MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates, *Int. Jour. of Energy & Techn.* 5 (4) (2013), 1–8.

18. T. S. Reddy, M. C. Raju & S.V.K. Varma, Unsteady MHD radiative and chemically reactive free convection flow near a moving vertical plate in porous medium, *JAFM*, 6 (3) (2013), 443-451.

19. M. C. Raju, S.V.K Varma, N. Ananda Reddy, Radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface, *J. Future Engg. and Tech.* 7 (2) (2012) 7-12.